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(19)

(54) METHOD AND APPARATUS FOR TESTING TRANSMISSION LINES AND CHANNELS

(71) We, THE POST OFFICE, a British body corporate established by Statute, of 23 Howland Street, London, WIP 6HQ, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the testing of transmission lines for telecommunications systems and, more especially, to the assessment of the variation of attenuation with frequency due to impedance irregularities in transmission lines, for example, wide band telecommunication cables, striplines and also waveguides.

It is known to investigate the variation of attenuation with frequency in a telecommunication cable by so-called substitution methods which involve looping the cable under test and comparing the cable loss with an attenuator. It is also known that narrow band variations in attenuation can occur in high-frequency transmission lines as a result of multiple reflection of the directly-transmitted signal by impedance irregularities within the line: this multiple reflection can give rise to an appreciable forward-echo signal which interferes with the directly-transmitted signal to cause the narrow band variations. In testing production lengths of cable (or othe forms of transmission line) for use in long distance high-frequency telecommunications systems it is necessary to ensure that these narrow-band effects are small enough not to disturb the performance of the complete system. However, assessment of the fine-structure of the attenuation/frequency variation in a transmission line by the known substitution methods is difficult due to the extreme precision with which measurements must be made.

The present invention provides a method of testing, at any predetermined part of the frequency spectrum, the attenuation due to even order multiple reflections in a channel of a transmission line for a telecommunications system, the method including the step of transmitting through the channel, to a receiver, a signal which comprises a burst of carrier wave whereby the received signal has a primary portion immediately succeeded by a secondary portion, the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only; the method also including the step of measuring the ratio of the amplitude of the secondary portion of the received signal to the amplitude of the primary portion, and thereby determining the attenuation of the signal due to even order multiple reflections within the channel.

The invention also provides a method of testing the atteunation due to even order multiple reflections in a transmission line for a telecommunications system, the method including the step of transmitting along the line, to a receiver, a sequence of signals each comprising a burst of carrier wave having a frequency within the range of frequencies to be tested whereby each received signal has a primary portion immediately succeeded by a secondary portion, the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only; the method also including the step of measuring, for each received signal, the ratio of the amplitude of the secondary portion to the amplitude of the primary portion, and thereby determining the attenuation of the signal due to even order multiple reflections within the transmission line. The frequencies of the signals constituting the said sequence may extend substantially continuously over the range of frequencies to be tested, or, alternatively, in discrete steps over the range of frequencies to be tested.

In each of the above methods provided by

the invention, the step of measuring the said ratio may include measuring the amplitudes of the envelopes of the secondary and primary portions or measuring the root mean square amplitudes of the secondary and primary portions. It will be appreciated, however, that the said ratio may be measured by comparing any parameter representative of the amplitude of the secondary portion with the corresponding parameter of the primary portion.

As regards the primary portion of the, or a, received signal, the amplitude (or representative parameter) may be sampled at any time during the duration of that portion. As regards the secondary portion, on the other hand, in order to eliminate the effect on the received signal of multiple reflections totally with the input lead or totally within the output lead of the transmission line, the amplitude (or representative parameter) is preferably measured after a time interval of at least $2t_r$ following the end of the primary portion, where t_r is the group propagation time within the input lead or the output lead of the transmission line, whichever is the longer, at the frequency of the burst of carrier wave.

To eliminate from the test measurements the effect, on the, or a, received signal, of multiple reflections between the input and output leads of the transmission path, and between the transmitter and the receiver, the amplitude (or representative parameter) of the secondary portion should be measured before the occurrence in the received signal of the echo component due to reflection of the burst of carrier wave within the output lead and then within the input lead of the transmission line. More particularly, the length of the burst of carrier wave should be such that the said echo component due to reflection of the burst of carrier wave within the output lead and then within the input lead does not occur until after the end of the secondary portion.

The invention also provides apparatus for testing, at any predetermined part of the frequency spectrum, the attenuation due to even order multiple reflections in a channel of a transmission line for a telecommunications system, the apparatus including means operable to generate a signal comprising a burst of carrier wave for transmission through the channel to a receiver to provide, at the receiver, a signal which has a primary portion immediately succeeded by a secondary portion the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only: the apparatus also including means operable to sample the amplitude of the received signal, or a parameter representative thereof, the said sampling means being adjustable to sample either the primary portion or the secondary portion of the signal.

Apparatus in accordance with the invention may be employed to test the attenuation due to even order multiple reflections in the transmission line (rather than just a channel thereof), in which case the generating means should be operable to generate a sequence of signals each comprising a burst of carrier wave having a frequency within the range of frequencies to be tested whereby each received signal has a primary portion immediately succeeded by a secondary portion. Preferably, the generating means is operable to generate a sequence of signals at frequencies which extend substantially continuously over the range of frequencies to be tested.

The generating means may, for example, comprise a sweep frequency source having a frequency range which includes the range of frequencies to be tested, the sweep frequency source having an output to a gating circuit to which a pulse generator is connected to apply enabling pulses. The pulse generator may be connected to the sampling means, through adjustable delay means, to operate the sampling means after a predetermined time following the generation of the, or each, burst of carrier wave. The sampling means may be connected to sample the, or each, received signal through an attenuator which is adjustable to calibrate the sampling means, and the apparatus preferably includes recording means connected to the sweep frequency source and to the sampling means to record the samples of the, or each, amplitudes of the received signal as a function of the frequency of the bursts of carrier wave.

By way of example, the invention will be described with reference to the accompanying drawings in which:

Figure 1 illustrates various envelope waveforms of bursts of carrier wave, and

Figure 2 is a block diagram of apparatus constructed in accordance with the invention for testing high-frequency telecommunications cables.

When a signal is transmitted along a telecommunications line, multiple reflection of the signal can occur at impedance irregularities within the line: if the signal at the input to the line is in the form of a burst of carrier wave, then even order reflections of the signal may give rise to an echo component which will interfere with the directly-transmitted component and cause an increase in the attenuation of the signal. In practice, it has been found that the echo component due to even order multiple reflections subtracts from the directly-transmitted component: theoretically, it is possible for the echo component to add to the directly-transmitted component but this has been found not to occur. The forward-scattered echo signal is

delayed relative to the directly-transmitted signal, but if the carrier-wave burst is sufficiently long a steady state will be reached in which the whole of the echo signal due to the even order reflections within the cable contributes to the transmitted waveform and will continue to arrive when the directly-transmitted signal has ceased.

This situation is illustrated in Figure 1 which shows:

(a) the envelope of a comparatively long burst of constant-frequency carrier wave at the input to a transmission line;

(b) the envelope waveform that would be received at the output of a uniform transmission line, and

(c) the envelope waveform which is received at the cable output of a transmission line when a forward-scattered echo signal exists and subtracts from the directly-transmitted signal.

As waveform (b) illustrates, the signal transmitted along a uniform line (that is, one which contains no impedance irregularities so that no multiple reflections occurs) is attenuated but is of the same length as the input signal (a). When multiple reflections occur, the echo component of the signal interferes with the directly-transmitted component, causing an increase in attenuation, and, as illustrated by waveform (c), continues to arrive at the output of the line when the directly-transmitted component has ceased so that the signal at the output of the line has a primary portion P of the same length as the input signal (a) and a secondary portion S which forms a tail to the envelope waveform. The primary portion P comprises the directly-transmitted component of the signal diminished by the echo component due to the even order multiple reflections, while the secondary portion S comprises the even order echo component only. The amplitude of the envelope of the secondary portion just after the end of the primary portion P corresponds to the component that has subtracted from the directly transmitted component and has been greatly exaggerated in Figure 1 for clarity: the envelope amplitude at this point could be up to 10% of the amplitude of the envelope of the directly-transmitted component of the signal and may typically be 1%.

The effect of multiple reflections and the resulting interference between the forward scattered echo and directly-transmitted components of the signal is that a fine structure in the form of small, frequency-selective peaks is imposed on the attenuation/frequency curve that would be exhibited by the transmission line in the absence of the irregularities giving rise to the multiple reflection echoes. The magnitude of these peaks can be assessed using the apparatus illustrated in Figure 2, in which the transmission line under test, (which in this case is a cable) is indicated at 1 and the leads by which the cable is connected at its input and output ends to the testing apparatus are indicated at 2 and 3 respectively.

A sweep frequency source 4 is connected to the input lead 2 of the cable 1 through a gating circuit 5 which is connected to receive enabling pulses from a pulse generator 6. This combination operates to provide a plurality of input signals to the cable 1 in the form of a sequence of bursts of carrier wave at frequencies throughout the frequency spectrum being tested. The output lead 3 of the cable is connected in an equalizer 7 which functions to eliminate the normal attenuation/frequency variation that would be present in a uniform cable while retaining the fine structure that is imposed thereon by even order multiple reflections, and also helps to minimize the effects of spurious output signals from the sweep frequency source 4. The output of the equalizer 7 is connected to a variable attenuator 8 which is used to calibrate the output signal of the cable as will be described below, and the calibrated signal is then fed, through a suitable amplifier 9 to one input of a sampling circuit 10 which, for purposes of illustration, may be taken to be a sampling oscilloscope. A second input of the sampling oscilloscope 10 is connected to receive the enabling pulses from the pulse generator 6 after a time interval imposed by a variable delay 11. The output of the sampling circuit 10 is connected to a detector 12 which, in turn, is connected to a plotter 13 which also has an input from the sweep frequency source 4. These various components of the apparatus shown in Figure 2 may each be of any suitable known type and, since they function in known manner, they need not be described further.

In use of the apparatus, the frequency source 4 is swept, at an appropriate rate, over the whole frequency range to be tested for the cable 1 and the output is gated by pulses from the generator 6 to apply, to the cable input lead 2, a sequence of signals each signal comprising a burst of carrier wave. The bursts are comparatively short so that the respective frequency of each burst is substantially constant, and the sequence of bursts covers the entire frequency range for testing the cable in discrete steps thereby enabling attenuation anomalies within that range due to even order multiple reflections to be detected. For each burst, the variable delay 11 is adjusted to be just greater than the length of the burst so that the signal received at the output end of the cable is sampled, at the oscilloscope 10, just after the finish of the primary portion, that is, at the point S′ on waveform (c) in Figure 1. The amplitude e_S of the envelope of the re-

ceived signal at this sampling point is sensed by the detector 12 and recorded, as a function of the respective frequency of that burst of carrier wave, by the plotter 13. To assist in this respect, the calibrating attenuator 8 is adjusted to place the sampled signal on an appropriate scale for measurement.

The variable delay 11 is then readjusted to be less than the length of the burst of carrier wave so that the received signal is sampled during the primary portion, that is, at any time during the portion P of the waveform (c) in Figure 1. The calibrating attenuator 8 is also readjusted to place this sampled signal on a scale which enables a comparison to be made conveniently with the previous sampling and the amplitude ε_p of the envelope of the received signal at this second sampling point is sensed by the detector 12 and recorder, as a function of the frequency of the burst of carrier wave, by the plotter 13. The increase in attenuation of the transmitted signal due to even order multiple reflections at impedance irregularities is then given by

$$a=20 \log_{10} (1-\varepsilon)$$

where a is the increase in attenuation and

$$\varepsilon=\frac{\varepsilon_S}{\varepsilon_P}$$

Repetition of these samplings for each burst will yield a measurement of the increase in attenuation due to echoes at each of a series of frequency steps extending over the whole frequency range of the cable.

The effects, on the samplings, of spurious output signals from the sweep frequency source 4 are minimized by the equalizer 7 as mentioned above. In the absence of the equalizer, the spurious signals (which are intermodulation products and undergo different degrees of attenuation in the cable 1) could give rise to an erroneous record at the plotter 13.

It will be appreciated that the attenuator 8 is required only for calibration purposes to obtain a measurement of the ratio ε of the amplitude of the envelope of the secondary portion of the received signal to the amplitude of the envelope of the primary portion. The attenuator need not, therefore, be a precision instrument as in known methods for measuring attenuation, in which attenuators are used for direct comparison purposes. Furthermore, since the quantity of importance in the determination of the increase in attenuation is the ratio ε, the envelope amplitude ε_p may be measured at any point during the primary portion P of the received signal (including the instant at which the portion P commences, when the echo component is zero) without any substantial effect on the accuracy to which the increase in attenuation a is determined, despite the small variation that occurs in ε_p as illustrated in Fig. 1.

In general, the method described above will yield the increase in attenuation a due to all the even order reflections at impedance irregularities within the cable 1 and the input and output leads 2, 3. These reflections comprise:

(i) Reflections totally within the input lead 2;

(ii) Reflections totally within the cable 1;

(iii) Reflections totally within the output lead 3;

(iv) Reflections between the input lead 2 and the cable 1;

(v) Reflections between the cable 1 and the output lead 3, and

(vi) Reflections between the input lead 2 and the output lead 3.

Reflections between the transmitting and receiving portions of the apparatus will also be included.

Reflections of types (iv) and (v) can be minimized, although not eliminated completely, by precise matching of the cable. In addition to this, however, it has been found that some of the other reflection types can be eliminated by a suitable choice of the lengths of the bursts of carrier wave that are applied to the cable input lead 2 and by a suitable choice of the time interval between the sampling point S′ (Fig. 1) and the end of the primary portion P of a received signal.

More particularly, it has been found that second-order reflections of types (i) and (iii) can be eliminated by spacing the sampling point S′ from the end of the primary portion of the received signal by a time interval t_r greater than twice the group propagation time of the input lead 2 or the output lead 3 whichever is the longer.

That is,

$$t_r > \frac{2l}{v}$$

where l is the length of the longest test lead and v is the group propagation velocity within the leads at the frequency of the burst signal.

On the other hand, it is also desirable that the time interval t_r should not be unduly large since this will result in a decrease in the accuracy of the resultant measurement, directly related to the loss per unit length of the cable 1: in practice, it has been found that it is possible to delay the sampling point S′ to an extent sufficient to eliminate the reflections taking place totally within the test leads 2 and 3 without significantly affecting the final measurement of the increase in

attenuation. For example, in a production length of 375 E cable (normally 300 m to 400 m with an upper limit of 800 m) at a frequency of 100 M Hz, and with a test lead length of the order of 2 m, a time interval t_r of 150 nS would typically be long enough to eliminate reflections totally within the test leads and would produce an attenuation of only 1 dB.

With regard to reflections of type (vi) that is, between the input and output leads 2, 3, and reflections between the transmitting and receiving portions of the apparatus, it has been found that the effect of these on the attenuation measurement can be eliminated by making the length of the carrier wave burst short enough to ensure that signals due to these reflections do not arrive at the cable output until after the measurement of the amplitude ε_S or even until after the end of the secondary portion *S*. The reflections under consideration can then be ignored, or removed by gating.

The method described above is of particular utility in the assessment of coaxial cables for use in long-distance, high-frequency f.d.m. (frequency-division-multiplex) systems where it is necessary to ensure that the effects of impedance irregularities within the cables are not significant enough to disturb the transmission performance of the whole system. The invention is, however, not restricted to use in connection with cables and may be employed in the assessment of, for example, strip lines and, indeed, transmission lines in general, including waveguides.

Although, in the apparatus shown in Fig. 2, the bursts of carrier wave applied to the cable 1 are not each of an absolutely constant frequency (being produced by gating the output of the sweep frequency source 4) it will be appreciated that this is not an essential feature, and that the sequence of bursts could each be of a respective absolutely constant frequency derived from a frequency generator varied in discrete frequency steps.

It will also be appreciated that although the method described above is concerned with attenuation measurements due to even order multiple reflections over the whole frequency range being tested for a cable it could easily be modified for application to a cable channel. In this case, a single sequence burst only of carrier wave (rather than a plurality of bursts of different frequencies) may be necessary to assess the attenuation due to scattering over the band width of the channel. It will be understood, however, that the general method of assessing the attenuation due to scattering in a channel will otherwise be similar to that described above and that the apparatus employed can be similar to that illustrated in Fig. 2.

WHAT WE CLAIM IS:—

1. A method of testing, at any predetermined part of the frequency spectrum, the attenuation due to even order multiple reflections in a channel of a transmission line for a telecommunications system, the method including the step of transmitting through the channel, to a receiver, a signal which comprises a burst of carrier wave whereby the received signal has a primary portion immediately succeeded by a secondary portion, the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only; the method also including the step of measuring the ratio of the amplitude of the secondary portion of the received signal to the amplitude of the primary portion, and thereby determining the attenuation of the signal due to even order multiple reflections within the channel.

2. A method of testing the attenuation due to even order multiple reflections in a transmission line for a telecommunications system, the method including the step of transmitting along the line, to a receiver, a sequence of signals each comprising a burst of carrier wave having a frequency within the range of frequencies to be tested whereby each received signal has a primary portion immediately succeeded by a secondary portion, the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only; the method also including the step of measuring, for each received signal, the ratio of the amplitude of the secondary portion to the amplitude of the primary portion, and thereby determining the attenuation of the signal due to even order multiple reflections within the transmission line.

3. A method as claimed in claim 2, in which the frequencies of the signals constituting the said sequence extend substantially continuously over the range of frequencies to be tested.

4. A method as claimed in claim 2, in which the frequencies of the signals constituting the said sequence extend in discrete steps over the range of frequencies to be tested.

5. A method as claimed in any one of the preceding claims, in which the step of measuring the said ratio includes measuring the amplitudes of the envelopes of the secondary and primary portions.

6. A method as claimed in any one of claims 1 to 4, in which the step of measuring the said ratio includes measuring the root

mean square amplitudes of the secondary and primary portions.

7. A method as claimed in any one of the preceding claims, in which the step of measuring the said ratio includes measuring the amplitude of the secondary portion, or a parameter representative thereof, after a time interval of at least $2t_r$ following the end of the primary portion, where t_r is the group propagation time within the input lead or the output lead of the transmission line, whichever is the longer, at the frequency of the burst of carrier wave.

8. A method as claimed in any one of the preceding claims, in which the step of measuring the said ratio includes measuring the amplitude of the secondary portion, or a parameter representative thereof, before the occurrence in the received signal of the echo component due to reflection of the burst of carrier wave within the output lead and then within the input lead of the transmission line.

9. A method as claimed in claim 8, in which the length of the burst of carrier wave is such that the said echo component due to reflection of the burst of carrier wave within the output lead and then within the input lead does not occur until after the end of the secondary portion.

10. Apparatus for testing, at any predetermined part of the frequency spectrum, the attenuation due to even order multiple reflections in a channel of a transmission line for a telecommunications system, the apparatus including means operable to generate a signal comprising a burst of carrier wave for transmission through the channel to a receiver to provide, at the receiver, a signal which has a primary portion immediately succeeded by a secondary portion the primary portion comprising a directly-transmitted component together with an echo component which is due to even order multiple reflections of the burst of carrier wave, and the secondary portion comprising an echo component only; the apparatus also including means operable to sample the amplitude of the received signal, or a parameter representative thereof, the said sampling means being adjustable to sample either the primary portion or the secondary portion of the signal.

11. Apparatus as claimed in claim 10 for testing the attenuation due to even order multiple reflections in the transmission line, the generating means being operable to generate a sequence of signals each comprising a burst of carrier wave having a frequency within the range of frequencies to be tested whereby each received signal has a primary portion immediately succeeded by a secondary portion.

12. Apparatus as claimed in claim 11, in which the generating means is operable to generate a sequence of signals at frequencies which extend substantially continuously over the range of frequencies to be tested.

13. Apparatus as claimed in any one of claims 10 to 12 in which the generating means comprises a sweep frequency source having a frequency range which includes the range of frequencies to be tested, the sweep frequency source having an output to a gating circuit to which a pulse generator is connected to apply enabling pulses.

14. Apparatus as claimed in claim 13, in which the pulse generator is connected to the sampling means, through adjustable delay means, to operate the sampling means after a predetermined time following the generation of the, or each, burst of carrier wave.

15. Apparatus as claimed in claim 13 or claim 14, including recording means connected to the sweep frequency source and to the sampling means to record the samples of the, or each, received signal as a function of the frequency of the burst of carrier wave providing those samples.

16. Apparatus as claimed in any one of claims 10 to 15, in which the sampling means is connected to sample the, or each, received signal through an attenuator which is adjustable to calibrate the sampling means.

17. Apparatus for testing the attenuation due to even order multiple reflections in a transmission line for a telecommunications system or in a channel thereof, the apparatus being substantially as described herein with reference to, and as illustrated by Fig. 2 of the accompanying drawings.

18. A method as claimed in claim 1 or claim 2, substantially as described herein with reference to the accompanying drawings.

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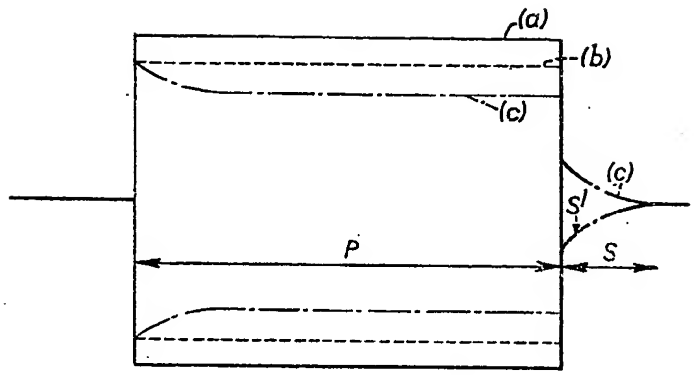

FIG. 1.

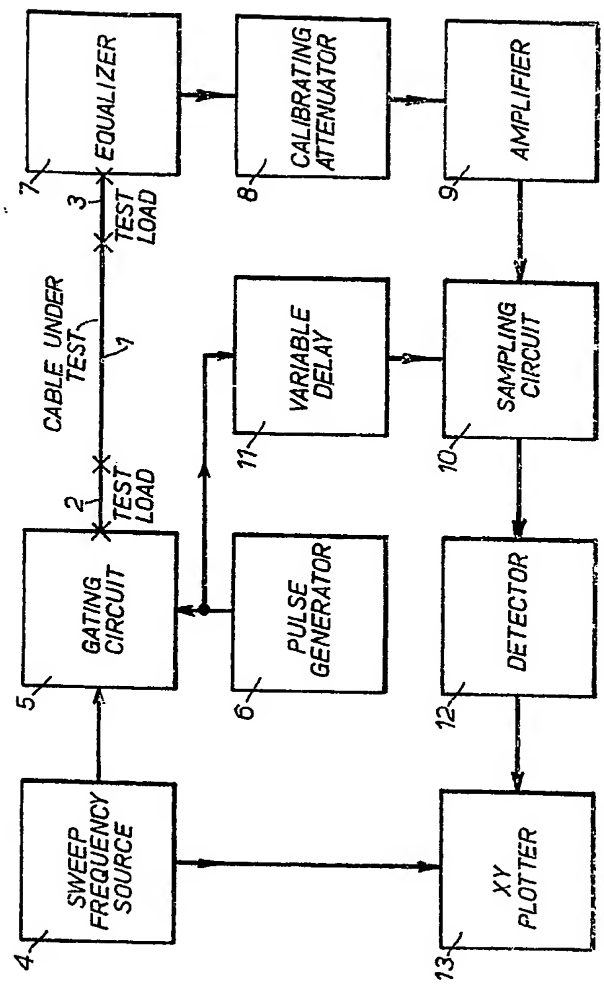
EQUALIZER
CALIBRATING ATTENUATOR
AMPLIFIER
CABLE UNDER TEST
TEST LOAD
TEST LOAD
VARIABLE DELAY
SAMPLING CIRCUIT
GATING CIRCUIT
PULSE GENERATOR
DETECTOR
SWEEP FREQUENCY SOURCE
XY PLOTTER
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FIG. 2.